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Mechanical Shock Resistance
of Threaded Fasteners

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ABSTRACT

An investigation was made of the mechanical shock resistance of K-Monel full-body studs set in HY-80 steel under various conditions. Strain gages mounted on the stud shanks were used to measure dynamic loading. Elastic nylon-insert monel stop nuts were used throughout the test. The data indicated that for the conditions of the test Loctite-coated 3A-3B threads are equal in shock resistance to uncoated 5A-5B threads, and that the elastic stop nuts are reusable after repeated shock.

ADMINISTRATIVE INFORMATION

This investigation was conducted under Sub-project S-F020 01 02 (formerly S-R007 09 02), Task 0857.

ADMINISTRATIVE REFERENCES

(a) BUSHIPS ltr R007 09 02 ser 634B-734 of 2 Aug 1963
(b) MEL ltr NP/10410(831) of 1 Apr 1964
(c) BUSHIPS ltr NObs 90493 ser 634B-962 of 1 Sep 1964
(d) BUSHIPS ltr S-R007 09 02 ser 634B-1431 of 6 Jan 1965
(e) MEL Spdltr NP/10410(831) Assigt 71 111 of 20 May 1965, to BUSHIPS
(f) MEL Spdltr NP/10410(710) Assigt 71 111 of 20 Jul 1965, to BUSHIPS
(g) MEL ltr NP/10310(710:ARS) Assigt 71 111 of 2 May 1966, to CO, Puget Sound Naval Shipyard
(h) BUSHIPS ltr 10361, ser 634B-921, of 27 Aug 1965, to Loctite Corp, Newington, Conn.
(i) Caplan, I. L., MEL R&D Rept 309/65, "Investigation of the Notch Sensitivity of Nickel Copper Aluminum (K-Monel) Rod", Sep 1965
(j) MEL ltr to BUSHIPS NP/9120(831) Assigt 71 111 of 7 Oct 1964

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MECHANICAL SHOCK RESISTANCE OF THREADED FASTENERS

1.0 INTRODUCTION

The Marine Engineering Laboratory has been conducting an investigation of the high impact shock resistance of threaded mechanical fastener systems. Of primary concern are fastener systems used for hull integrity installations in submarines. The program was originally outlined in reference (a). Reference (b) presented the Laboratory's proposal for conducting the investigation. The program was further amplified in references (c) and (d), which were based on conferences of BUSHIPS and MEL representatives.

The preliminary finds of the investigation were reported in references (e) and (f), and additional information was given in reference (g). The data were discussed in reference (h). The report on notch-sensitivity was submitted in reference (i). This report presents the present status of the shock investigation.

2.0 BACKGROUND

Of four "Approaches" for related investigations stated in reference (a), Approaches "C" and "D" covered shock and vibration studies as follows:

"C" - Study the strength and holding properties of self-locking nuts under various conditions of stress including static, vibration, and shock loading. For the purpose of this study, plastic deformation of nut threads constitutes failure.

"D" - Study the effects of variables such as installation method, thread form, condition, lubrication and coatings; reusability; contour of mating surface; and type of locking element.

2.1 Scope. The approach section of reference (b) restated the foregoing approaches and included bolts and studs in the program for nuts described in Approach "D". Reference (c) contracted with the Value Engineering Company to perform the static requirements of the program. Thus static tension tests conducted by MEL would be only those necessary to directly support the shock work, and those tests required for a notch-sensitivity study.

Four factors of primary concern were spelled out in reference (b):

- determination of the stud engagement required for K-Monel and monel studs in various materials.

- study of the material damage resulting from the interference fit of Class 5 threads.

- effect of stud design on strength and holding properties.

- effects of installation and design factors on the holding properties of self-locking nuts (nylon-insert type) under various stress conditions (static, vibration, and shock loading).

A desire to compare 3A-3B and 5A-5B threads for stud setting, plus a lesser interest in 2A-2B threads, was indicated in reference (d). Of immediate interest were K-Monel studs set in cast monel hull fittings to secure bronze flanges. Further, the required testing was divided into four groups, I through IV, of which I and II are related to a "basic setup". The "basic test setup" was as follows:

- K-monel stud.

- HY-80 rolled steel drilled and tapped with Class 5B threads.

- HY-80 rolled steel in clamp loading.

- stud set threads Class 5A fit.

- stud set end roll threaded.

Group I involved fastener sizes of 1/2", 3/4", 1", and 1-1/4" diameters. Group II involved fastener sizes of 1-1/2", 2", and 2-1/2" diameters. Group III involved fastener sizes of 3/4", 1", and 1-1/4" diameters with varied fastening conditions. Group IV involved fastener sizes of 1-1/2" and 2" diameter, also with varied fastening conditions. The fastening variables included:

- bolt material

- clamp load material

- thread fit on stud set end

- thread locking compound.
- rolled versus cut threads.
- thickness of clamped load.

It was desired that data accumulated during shock testing should, when evaluated, show for each bolt size and condition:

- the minimum shock level at which loss of bolting prestress would occur.
- the shock level at which loss of prestress is significant.

2.2 Purposes. The overriding objectives of the program were to determine:

- is a stud set in an "anti-lubricant" (Loctite) coated 3A-3B thread installation as shock resistant as a stud set in an uncoated 5A-5B thread installation.
- what level of preload is required for equal shock resistance.
- whether an elastic stop nut is as shock resistant as a plain nut.
- whether an elastic stop nut is reusable after repeated impact.

In accomplishing either or all of the above, a reliable criterion for failure of the fastener system was essential. Likewise, it was important that the method for establishing the preload be reliable. Angle turn of the nut and calibrated torque wrench methods were rejected in favor of strain gage instrumented studs since strain is a directly measurable phenomenon.

2.3 Limitations. For the purposes of this study, loss of more than 50 percent of the preload on a stud as a result of shock was arbitrarily considered as failure of the fastener assembly. Preload values of 90 percent and 75 percent of the 0.2 percent yield strain calculated for the root section were used for the investigation. The calculations were based on strain measured on the shank during tension tests of sample studs. Preload and loss of preload during the shock tests were indicated by strain gages mounted on the bolt shanks. Discussions of the strain gaging technique and

the choice of root section for strain references appear elsewhere in the report.

The several types of failure involved in threaded fastener systems vary in seriousness according to the relative ease of repair. Possible failure modes are listed below in the order of repair difficulty, with the most easily corrected failure given first:

- stripping of internal threads of nut.
- stretching of stud or fracture occurring in shank or nut thread.
- stripping of stud threads.
- stripping of foundation threads (in which stud is set) or fracture of stud in stud set threads.

Another way of describing the preferred failure mode would be that the stud threads should be stronger than the stud shank, which should in turn be stronger than the nut threads.

3.0 MATERIALS

Materials as described below were scheduled for use in the overall fastener investigation. The stud and nut designs conformed to the requirements of reference.[1]

Nuts:	R-Monel[2]
	Grade 8 Carbon Steel[3]
	F-303 Corr. Res. Steel[4]
Studs:	K-Monel, age hardened[5, 6, 7]
	R-Monel
Stud Adapter:	HY-80 (HiWay) steel
	Cast Monel*

[1]Superscripts refer to similarly numbered entries in Appendix A

Load Clamp: HY-80 (HiWay) steel

Bronze*

Lubricant: Machine oil

Anti-lubricant: "Loctite" locking compound[8]

*to simulate hull fittings as in BUSHIPS dwg 1385947 Rev. A

4.0 TEST PROCEDURES

Specimen K-Monel studs were instrumented with strain gages and statically loaded in tension to failure on a universal testing machine. The load, strain, stress, and deflection data were correlated to determine levels representative of the 0.2 percent yield strain value for the various sizes of K-Monel studs in use for the test. These values were determined from gages mounted on the stud shank near the tap end, but were correlated insofar as was possible with the values occurring at the root of the thread. Shank strains were correlated with loads and with calculated percent of yield strain for root sections. Detailed discussions of strain gaging, shank and root section relationships, and stress raisers appear in Section 6.0 of this report. Figure 1 and Tables 1 and 2 give pertinent information on the tensile tests and preload.

4.1 Groups. The original program (Groups I through IV) called for the testing of studs ranging from 1/2" through 2-1/2" diameter. In view of the very high securing torques required for the larger sizes, and the unavailability of HY-80 material in the thicknesses required for full stud engagement in the larger sizes, it was decided to limit the initial investigation to studs of 1-1/4" diameter and less. Thus, the actual program covered Groups I and III only, although no tests have yet been conducted on 1-1/4" studs. Table 3 and Figure 2 present design information on the studs.

4.2 Fixture. A test fixture for shock was fabricated as shown in MEL drawing 16671, reference (j). This fixture involved a base plate containing a single stud adapter bolted to the table of the Navy Standard Medium Weight Shock Machine.[9] A load plate was lowered over the stud, followed by a load clamp compatible with the base-plate adapter. The base-adapter-load-clamp system was designed to assure full thread engagement, i.e., complete insertion of the tap end of the stud, to assure

availability of the full strength of the stud. Strain gage leads were brought out through the clamp, and an elastic stop nut was installed on the stud. Additional load plates were later installed as required. The load plate, clamp, additional load plates (and attached bolt and nut hardware) comprised the inertia load of the fastener assembly. Tables 4, 5, and 6 present pertinent inertia load and associated shock information, relative to the test installation and to the schedule of shock blows administered.

Table 1

Tension Test Data for Typical Studs*

Nominal Diameter, inch	1/2	3/4	1
Shank diameter, inch	0.502	0.747	1.000
Root diameter, inch	0.405	0.620	0.846
Shank section area, in^2	0.198	0.438	0.785
Root section area, in^2	0.129	0.302	0.563
Handbook Stress**Area, in^2	0.143	0.334	0.608
Point of Deviation of load strain curve from linearity:			
(Shank) load, lb	12,300	30,500	52,000
Shank, strain, μin/in	2,450	2,650	2,600
Shank stress, psi***	62,100	69,650	66,250
0.2% offset yield:			
(Shank) load, lb	17,400	41,700	69,500
Shank strain, μin/in	5,450	5,650	5,400
Shank stress, psi	87,000	95,000	88,000
Fracture load, lb	20,450	46,100	83.700

* All strain measurements made by gages at shank near tap end threaded section.

** Reference H-128 Screw Handbook

***Abbreviations used in this text are from the GPO Style Manual, 1959, unless otherwise noted.

Table 2

Preload Data for Studs*

Nominal stud diameter, in	1/2	3/4	1
90% Preload:			
(Shank) Load, lb	10,200	25,900	45,000
Shank Strain, μin/in	2,000	2,250	2,250
Shank Stress, psi	51,000	58,850	57,300
75% Preload:			
(Shank) Load, lb	8,300	21,500	37,500
Shank Strain, μin/in	1,650	1,875	1,875
Shank Stress, psi	41,500	48,850	47,800

*The stud is preloaded to the indicated strain value by torquing of the nut (on the stud) against the clamped load.

Table 3

Stud Dimensions

Stud Size Code Letter	Nominal Stud Size inch	Tap* End Threads	Nut** End Threads	Tap End Length inch	Shank Length inch	Nut End Length inch	Total Length inch	Nut Length plus Shank Length inch	Shank Section Area sq. in
A	1/2	13 NC	13 NC	3/4	3/4	1 1/2	3	2 1/4	.196
B	3/4	10 NC	10 NC	1 1/8	1 5/8	2	4 3/4	3 5/8	.442
C	1	8 NC	8 NC	1 1/2	2 1/4	2 1/2	6 1/4	4 3/4	.785
D	1 1/4	7 NC	7 NC	1 7/8	2 7/8	3	7 3/4	5 7/8	1.227
E	1 1/2	6 NC	6 NC	2 1/4	3 1/2	3 1/2	9 1/4	7	1.767
F	2	4 1/2 NC	4 1/2 NC	3	4 3/4	4 1/2	12 1/4	9 1/4	3.142
G	2 1/2	4 NC	4 NC	3 3/4	6	5 1/2	15 1/4	11 1/2	4.909

* Tap end - half of studs Class 5A and half of studs Class 3A
** Nut end - all Class 3A

Table 4

Inertia Load Data for Stud Shock Tests

Nominal stud diameter, in	1/2	3/4	1
Clamped Weight (inertia load), lb	260	310	760
Stress in stud due to force equal to inertia load:			
Shank, psi	1300	710	970
Root, psi	2000	1030	1350
Total load on shock machine, lb	565	615	1015
Equivalent static acceleration* required to equal the 90% preload, G	39	83.5	59.2

*Ratio of load required for 90% preload shank strain to above inertia load.

Table 5

Shock Schedule

Schedule of shock runs on the medium weight shock machine (table travels were 1.5" in all except three tests).			
Height of Drop of Hammer (inches)	1/2 inch studs	3/4 inch studs	1 inch studs
2	X	—	—
3	X	—	—
3 1/2	X	—	—
4	X	—	—
4 1/2	X	—	—
5, 5, 5	XXX	X	X
6	—	X	X
7	—	X	X
8	—	X	X
9, 9	—	X	XX
10	—	X	X
11	—	X	X
12	—	X	X
13	—	X	X
14	—	X	X
15	—	X	X

Table 6

Inertia Loads and Velocity and Acceleration Data

Stud Size	Clamped Load lb	Total Load on anvil table of machine (lb)	Initial Upward Table Acceleration (1)(2)(3)(4)G 6"drop	9"drop	12"drop
1/2	260	565	175	215	250
3/4	310	615	175	215	250
1	760	1015	175	215	250

NOTES:

(1) Hammer impact velocities varied from 5.7 ft/sec for 6" drop
to 6.95 ft/sec for 9" drop
to 8.0 ft/sec for 12" drop

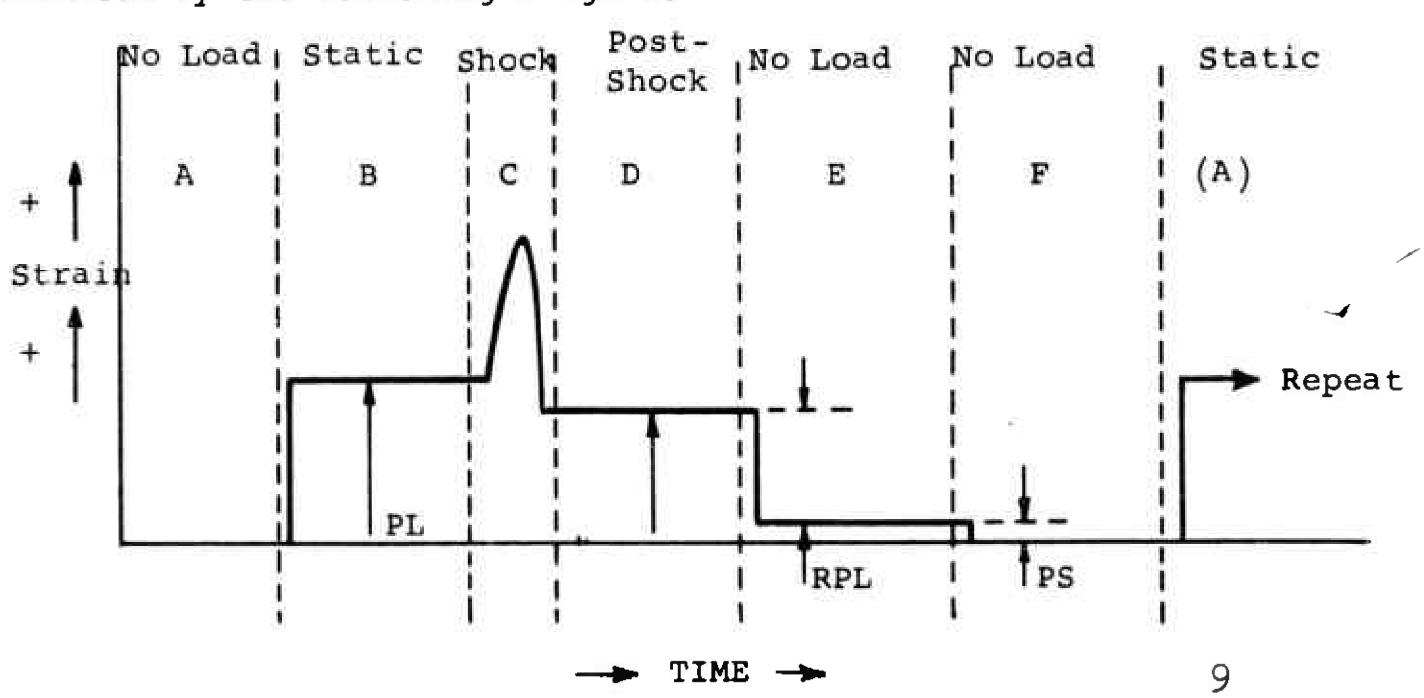
(2) Average upward table velocity over the 1.5" or 3" table travel was approximately: 3.9 ft/sec for 6" drop
4.7 ft/sec for 9" drop
5.4 ft/sec for 12" drop

(3) Average downward velocities were 2.2, 3.25, and 3.85 ft/sec.

(4) This is input at base of stud shock test fixture and it results in upward motion of the entire anvil table and fixture toward the stops.

The deceleration experienced by the table upon impact at the stops is responsible for the tension shock loading of the stud. The pertinent G values were not determined.

4.3 Loading. The static and dynamic loading of the stud and nut assembly during a shock test occurred sequentially as indicated by the following diagram:



EVENTS	DESCRIPTION
A	No load or strain on the stud.
B	Torquing of nut loads stud to the predetermined elastic tension strain for preload, PL.
C	Shock, primarily tension, resulting from impact of shock table against "stops" of shock machine.
D	Apparent remaining preload; contains permanent strain component, and therefore not valid without correction.
E	Manual loosening of nut to determine the remaining preload, RPL.
F	Rebalance of strain gage bridge to determine permanent stretch, PS, of shank of stud.
(A)	Retorque to preload elastic tension strain and repeat.

(Figures 3 and 4 show typcial shock records obtained during the tests.)

The procedure for determining the actual remaining preload strain and for facilitating setting of the same preload strain for the next shock run necessitated the loosening of the nut after each shock run. In actual post-shock maintenance aboard ship, the nuts would, of course, not be loosened, but would instead be tightened. Thus, the test procedure does not exactly reproduce service actions. However, there is no other practical method for obtaining the desired information on change in preload.

The loosening and retightening procedure was beneficial from the standpoint of providing supplementary information on nut reusability. Good reusability characteristics of the elastic stop nuts were indicated on the basis of their performance after relatively large numbers of tightening, loosening, and retightening operations.

4.4 Instrumentation. Strain signals were fed through a CEC strain gage amplifying system and readout was on a CEC recording oscillograph. Some acceleration measurements were made early in the test but were discontinued upon failure (fracture) of the accelerometers.

5.0 RESULTS

Additional shock tests of threaded fastener systems involving a single stud test fixture mounted on the standard Navy medium weight shock machine confirm the findings reported in references (f) and (g).

For K-Monel studs, age-hardened, with the tap-end driven into HY-80 plate, with monel elastic stop nuts torqued on the nut end above the clamped load (clamp also HY-80), with 90 percent preload (based on near-the-tap-end shank strain-gage readings indicating 90 percent of the 0.2 percent offset yield strength stress at the root section area), there is no significant difference between the Loctite coated Class 3 studs and the Class 5 studs uncoated, as regards the loss of preload due to shock.

Plots of the preload (shown as percent of 0.2 percent yield) remaining after shock versus percentage of the 0.2 percent yield stress load incurred during shock are presented in Figures 5, 6, and 7, for 1/2-inch, 3/4-inch, and 1-inch studs. As would be expected, a negative slope resulted for the plots in each size. There was considerable scatter of the data for the 1/2-inch studs, less scatter for the 3/4-inch studs, and the least for the 1-inch. The slopes were progressively less steep with increase in stud size, and the data became more closely linear with increase in size. Typical shock test data and curves are presented in Table 7 and Figures 8 and 9.

6.0 DISCUSSION

Consideration of many other factors and a more detailed analysis of existing data are needed for a complete understanding of the shock resistance (transient response) of threaded mechanical fastener systems. In order to provide a comprehensive authoritative statement as to the equality of shock resistance of uncoated Class 5 threads and Loctite coated Class 3 threads, the following work should be completed:

- accumulate more data to allow a statistical analysis.

- provide data in terms of energy.

- determine actual relationship between shank strain, strain for the standard "stress area", strain in the root, and elongation of the stud.

- account to some degree for the effect of the stress raiser in the threaded section and determine the significance of notch sensitivity.

- determine proper ratio of the weight of the clamped load to the size of the stud.

- study the effect of different clamping conditions and materials.

- determine the difference in results between single and multi-stud tests.

- study the influence of the loading sequence of the medium weight shock machine as compared to actual shipboard installation.

- more closely define failure and determine the minimum level of preload required for equality in shock resistance for Loctite coated 3A-3B threads and uncoated 5A-5B threads.

6.1 Gage Strain and Load Relationships. Initially, it was planned to compare mechanical fastener systems on the basis of preloads equivalent to various percentages of the conventional 0.2 percent yield stress load. All studs were instrumented with strain gages to facilitate determination of the desired load-stress values. Figure 1 shows typical load versus strain curves for K-Monel, the primary material, with the various preload percentages indicated. In accordance with standard acceptable practice the 0.2 percent offset yield value was used for refence. However, it was realized that all materials do not have easily identifiable elastic limits. It is probably that 0.1 percent would be more realistic.

6.1.1 The question of where on the shank of the studs to position strain gages was considered carefully and stress correlations were made with the aid of static tension tests. Initially, two gages were positioned axially 180 degrees apart, on the same circumferential grid line in close proximity to the threaded section, tap end. The intent was to compensate to some extent for possible bending, and to detect at the earliest possible moment the yielding which would occur at the root section of the threaded area. Most studs were instrumented in this manner. Bending strain compensation was accomplished thereby in only one plane, and, due to the proximity of the gages to the threads, the complete validity of the strain data in subsequent shock tests may be somewhat questionable because of the magnitudes of incurred nonlinear strains. Studs for all but the 1/2-inch size were instrumented in later tests for two-plane compensation. A later investigation of the static response of gages involved diametrally opposite gages

Table 7

Hi-Shock Test Data for 1-inch K-Monel
Stud with Elastic Stop Nut
(Shock Tests of 1"-8UNC K-Monel Stud Set in HY-80)

A = Class 3 - Loctite - 90% Preload
B = Class 3 - Studlock - 90% Preload
C = Class 5 - 90% Preload
D = Class 5 - 90% Preload
Table Travel 1.5 inch
90% Preload as indicated by shank strain = 2250 μin/in

Hammer Drop Height inches	Before Shock Pre-load Torque of Nut ft-lb (1)				After Shock Release Torque of Nut ft-lb				Elongation of stud (measured with depth gage) inches	
Zero	A	B	C	D	A	B	C	D	B	D
5	540	500	590	550	LOW	320	450	420	.001	.005 (2)
6	520	500	520	530	390	330	410	420 (2)	.008	.002 (2)
7	550	440	540	520	450	260 (2)	410	---	.007	----
8	520	500	540	530	360	280	360	320	.002	----
9	520	480	600	520	300	250	380	290	.005	.006 (2)
9	X	X	X	520	X	X	X	400 (2)	X	.002 (2)
10	530	490	600	510	280	170	330	220	.005	.003
11	550	480	580	520	230	140	330	120	.008	.004
12	550	460	630	540	200	75	290	130	.013	.017
13	580	440	600	550	180	30	240	80	.015	.009
14	530	450	560	520	50	30	160	20	.015	.017
15	550	X	630	X	80	X	120	X	X	X
								Total	.079	.071

NOTES:
(1) Inertia weight was 760 pounds.
(2) This test run was with 3" Table travel.
General: The nut was loosened after each shock and torqued up to preload for next shock.

placed as described above with another pair similarly located on a circumferential gridline at midlength of the shank. From these later static tests it was determined that the first indication of yielding (as shown by deviation from linearity of the load versus average axial strain curve) occurred for the same strain level but at a higher load for the near-thread gages.

6.1.2 For 1-inch K-Monel studs, a slight deviation from linearity of the load-strain curve begins in the vicinity of 54,000 pounds load. Near 60,000 pounds the deviation is more pronounced, particularly for the near-thread gages. At 72,000 pounds the midshank gages indicated approximately 4600 μin/in whereas the near-thread gages indicated approximately 6700 μin/in and reflected the effect of close proximity to the threaded section. The 0.2 percent offset (permanent deformation or residual strain of 2000 μin/in) was reached at 74,000 pounds as indicated by the midshank gages. This corresponds to a conventional stress of 94,000 psi. Tables 1, 2, and 8 show pertinent static loads for stud sizes tested. This value is compatible with those reported in the Value Engineering Company reports.[10] Table 8 lists experimentally-determined data for static strengths of K-Monel studs of sizes 1/2-inch, 3/4-inch, 1-inch, and 1-1/4-inch. It should be noted that shank gages serve only as indicators of strain conditions in the threaded section.

6.1.3 It can be concluded from these data that as soon as the indicated elastic limit for the material is exceeded, "load" is not a reliable reference for the comparison of stud strengths. This probably holds true for both static and dynamic loading conditions. From a purely materials perspective it is important to consider the stress and strain relationships at the root of the pertinent threaded section. However, insofar as shock resistance is concerned, the loads involved that are related to stud size, stud design and stud material are also important. This does not mean that the root status is ignored, but rather that all data for design and application of mechanical fastener systems must be presented in a usable form based on easily identificable factors.

6.1.4 The response of the threaded section is similar to that of a rod with a circumferential groove or circumferential notch, where axial loading is concerned. Because of this, no shank strain measurement is directly comparable to the strain associated with the root of the thread. The gage lengths over which the strains are incurred are vastly different, with that in the root of the thread being extremely small. Because of this and all foregoing considerations, it is believed that, when stud or bolt material is known to have a definite point of departure from linearity in a load-strain relationship, the load for this point of departure would be a better reference for shock resistance of fastener systems than the conventional 0.2 percent yield stress equivalent load. The former would provide a greater factor of safety.

Table 8

Load/Strain Data

Shank Stud Size	Load for Elastic Limit at Shank Mid-length lb	% of 0.2% Offset Load	Elastic Limit Strain in Shank μin/in	Load* for 0.2% Offset at Shank Mid-length lb	% of Fracture Load	Total Strain on Shank at Mid-length μin/in	Fracture Load lb
1/2	12,000	62	2,400	19,500	95	5,450	20,450
3/4	31,000	75	2,700	41,500	90	5,650	46,100
1	54,000	73	2,700	74,000	--	5,500	----
1 1/4	85,000	75	2,800	113,500	--	5,600	----

*Percentage Loads of 0.2% Yield Stress Load
(As indicated by midlength shank gages)

%	1/2 inch stud lb	3/4 inch stud lb	1.0 inch stud lb	1 1/4 inch stud lb
50	9,750	20,750	37,000	56,750
60	11,700	24,900	44,400	68,100
70	13,650	29,050	51,800	79,450
75	14,650	31,150	55,500	85,150
80	15,600	33,200	59,200	90,800
90	17,550	37,350	66,600	102,150
100	19,500	41,500	74,000	113,500

With Stress Raiser
Percentage Loads of 0.2% Yield Stress Load
Calculated for the Elastic Stress Concentration
Factor 2.0 Considered for the Threaded Section,
Relative to the Shank

%	4,880	10,380	18,500	28,400
50	5,850	12,450	22,200	34,050
60	6,830	14,500	25,900	39,750
70	7,330	15,580	27,800	42,580
80	7,800	16,600	29,600	45,400
90	8,780	18,680	33,300	51,100
100	9,750	20,750	37,000	56,800

The influence of the stress raiser in the threaded section must not be overlooked. This increases the strain in the threaded section over that indicated by shank gages (see Table 8). Technical references (1) and (2) of Appendix A indicate that for threaded sections there exists an elastic stress concentration factor ranging from 1.6 to 2.4. Future tests of studs should be conducted with consideration of an elastic stress concentration factor of 2.0 for averaging purposes. In the final analysis of the fastener assembly, the load per bolt limitation based on elastic performance will probably be the deciding factor in predicting the strength level of a fastener system.

6.1.5 To avoid loosening of a bolted assembly the elastic range for preloading should be no less than the anticipated load range.* On the other hand, the equipment being supported or restrained by the fastener system might be better protected from damage under severe shock if the fastener system were to deform plastically. This apparent incompatability of requirements is usually compromised by relegating deformation to foundations or mounts and keeping the transmitted peak shock force within the elastic preload range. Quite possibly, in most cases, fastener systems, bolts, studs, etc., may have to be increased in size and elastic strength in order to meet increasing shock resistance requirements.

6.2 Supported Weight (Static or Inertia Load for Shock Tests). Reflections based on test results have led to a belief that the original test loads (static - - - supported or clamped loads) were not as proportionate to bolt size as would be desirable. Therefore, it is considered that if this investigation should be continued, a supported or clamped load of such value should be used that the per stud load, if supported axially, would provide an axial stress, of 1000 psi in the shank of the stud.

With consideration given to an elastic stress concentration factor of 2.0 in the threaded section, the elastic stress in that section would then be 2000 psi for this load.

Figure 10 shows the axial load per stud for 1000 psi and 2000 psi as related to shank sectional area.

*The anticipated load range can be determined from correlating accelerations measured in ship shock trials and major shock experiments with inertia loads (equipment weights) and fastener sizes.

6.3 Multi-Stud Test Fixture. The test fixture originally used in this investigation provided for the test of only one stud at a time. This resulted in less data than might be desired and in too much time required per test. Therefore, to reduce testing time and costs, and to expedite data accumulation, the fixture was modified to allow multiple simultaneous tests as follows (in stud sizes 1" diameter or less):

Stud Size	Number of Studs per Test
1/2	4
3/4	3
1	2
1-1/4	1

The methods for clamping the load in the new fixture were unchanged, except that means for increasing the load and avoiding flexure of the component parts of the load were included.

7.0 CONCLUSIONS

While the investigation was not completed, certain conclusions can be drawn. For the loading conditions of the tests, and for the materials and stud and nut sizes tested, it is concluded that:

- the shock resistance of Loctite treated 2A-2B threads is not equal to that of untreated 5A-5B threads.

- the shock resistance of Loctite treated 3A-3B threads is equal to that of untreated 5A-5B threads when both associated studs are torqued to 90 percent of the established 100 percent preload axial strain.

- insufficient data exist for preloads of 75 percent to determine whether or not the shock resistance of Loctite coated 3A-3B threads and uncoated 5A-5B threads are equal when torqued to 75 percent of the established 100 percent preload axial strain.

- the elastic nylon insert stop nuts have a high degree of reusability.

8.0 FUTURE INVESTIGATION

This investigation has not been funded for Fiscal Year 1967 and no additional work has been planned. If there is a continued need for information in this area, and if the investigation should therefore be reopened later, it is suggested that the following be included:

- The related items of investigation outlined in the discussion (paragraph 6.0).

- An extension of the investigations to preloads less than 90 percent.

- Study of the shock performance of studs set in cast monel and clamping bronze flanges.

- Relating the shock data to energy units.

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Notes:
1 - 1" 8UNC K-Monel Stud
2 - Tensile Load at Fracture = 83,700
3 - Shank - 1.000" Diameter = .785 in^2 area
4 - Root of Thread - .846" Diameter = .563 in^2 area

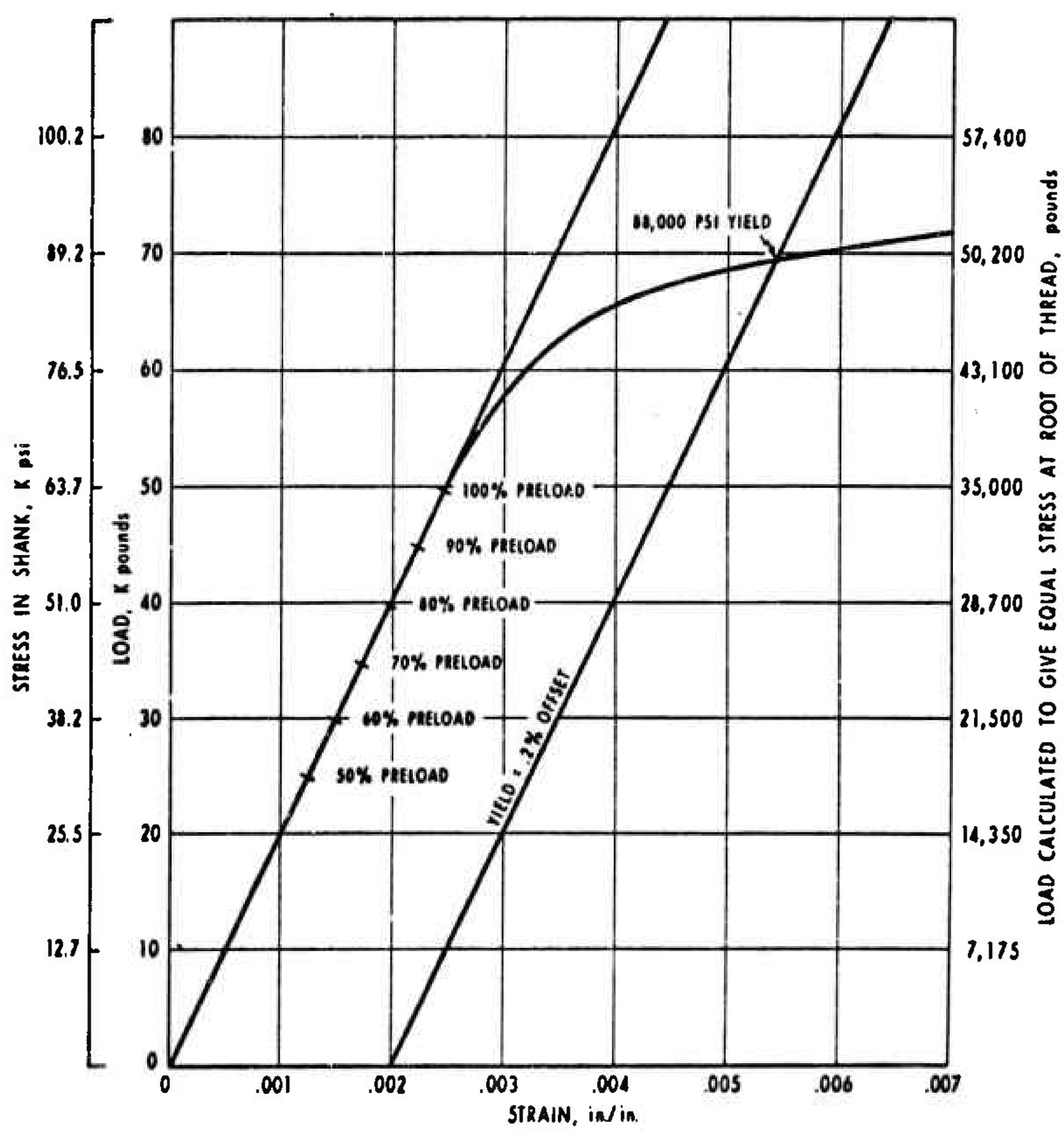

Figure 1

Force, Stress, Strain Relationships

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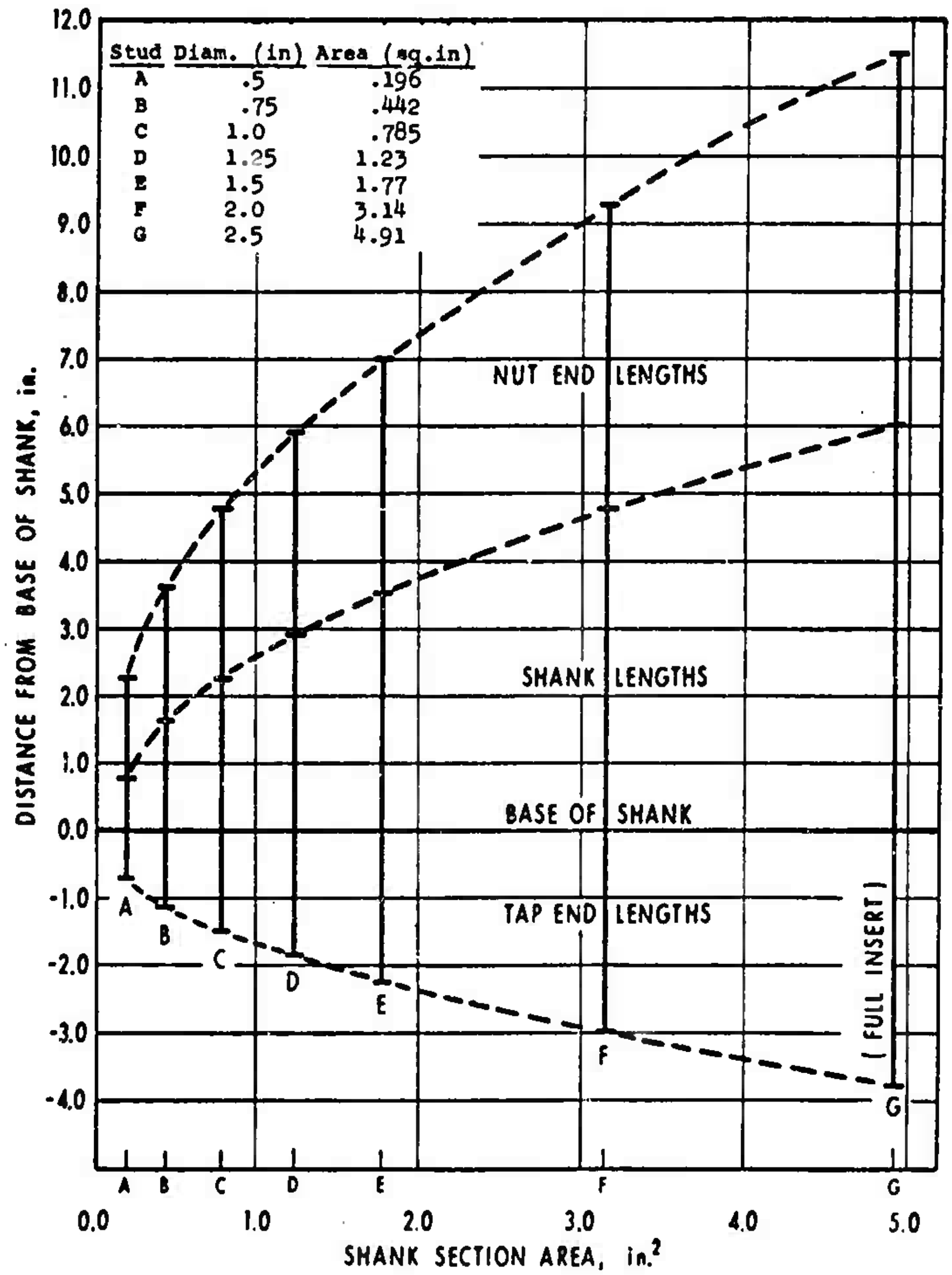
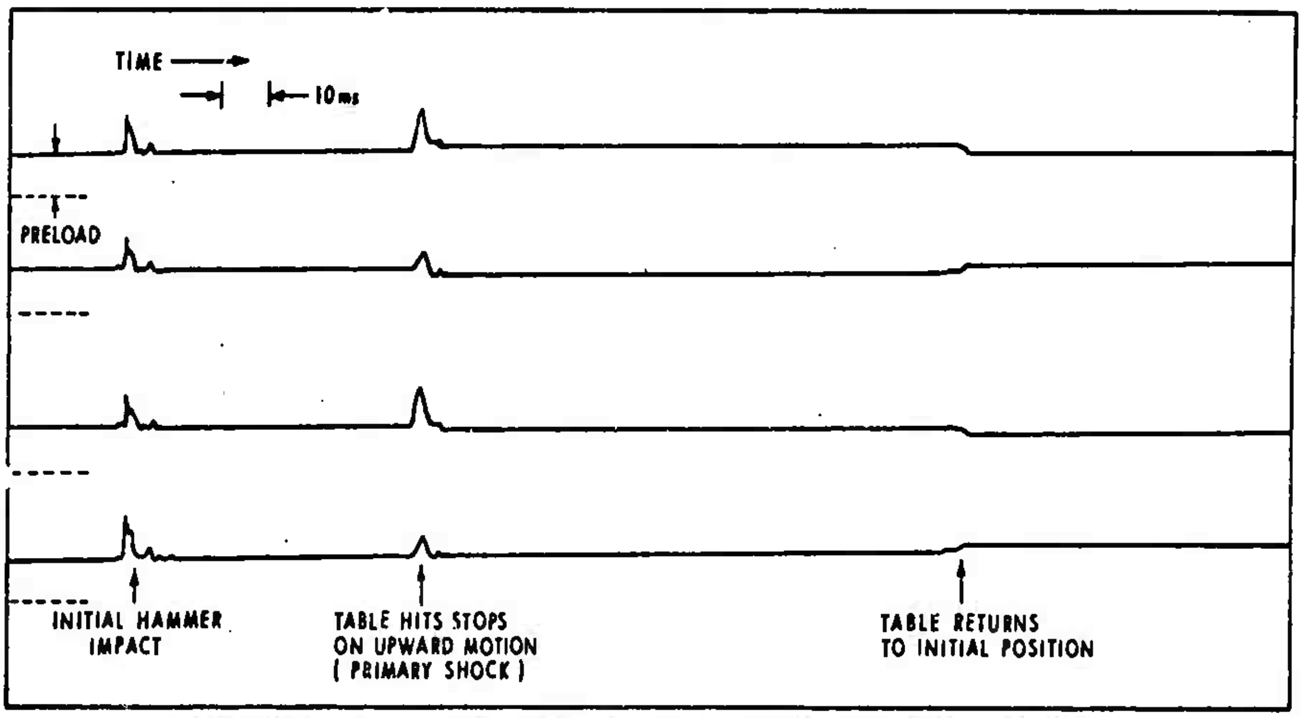


Figure 2

Stud Size Design Guide: Stud Lengths vs Shank Section Area



*Two separated groups of load plates on either side of the stud & load clamp produced flexure during initial hammer impact and resulted in eccentric end undesired loading.

Figure 3

Typical Shock Record for Initial Tests Utilizing Unbracketed* Load Plates (as shown in reference (i))

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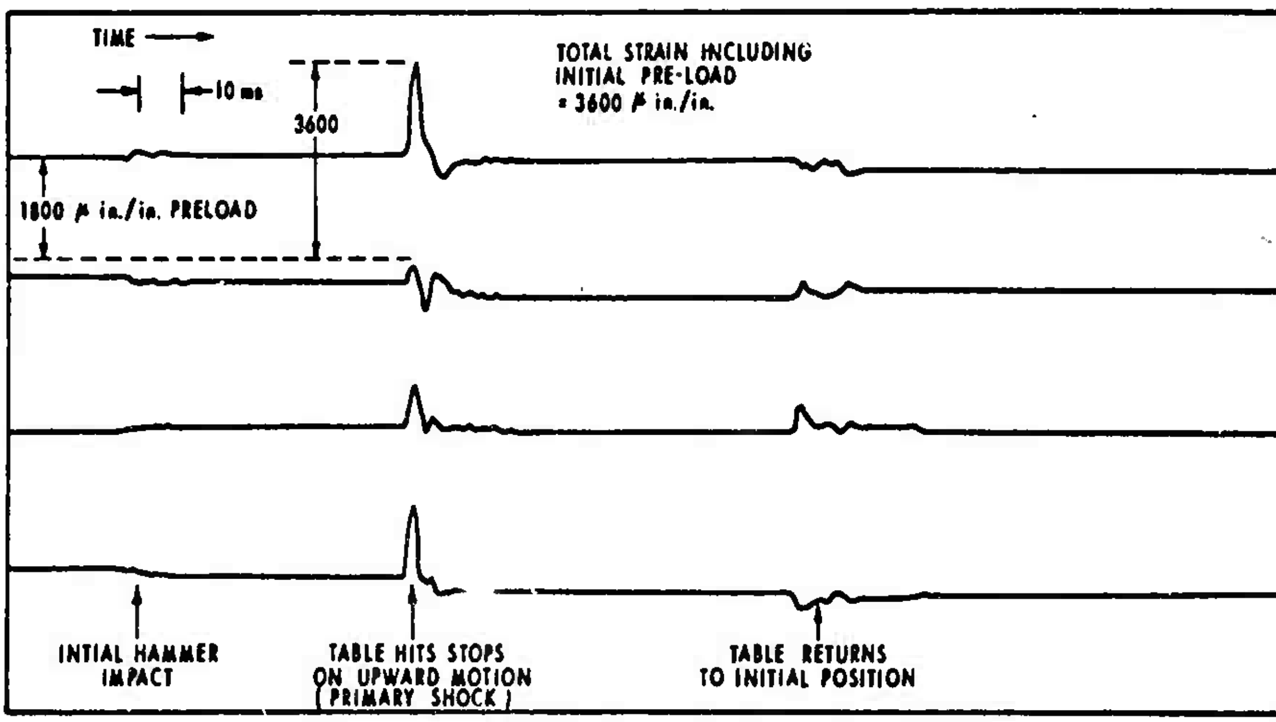

*Two restraining bars were installed across the two groups of load plates to prevent eccentric loading during initial hammer impact.

Figure 4

Typical Shock Record for Later
Tests with Bracketed Load Plates*
1" stud, 6" drop, 3" table travel
575 ft-lb torque

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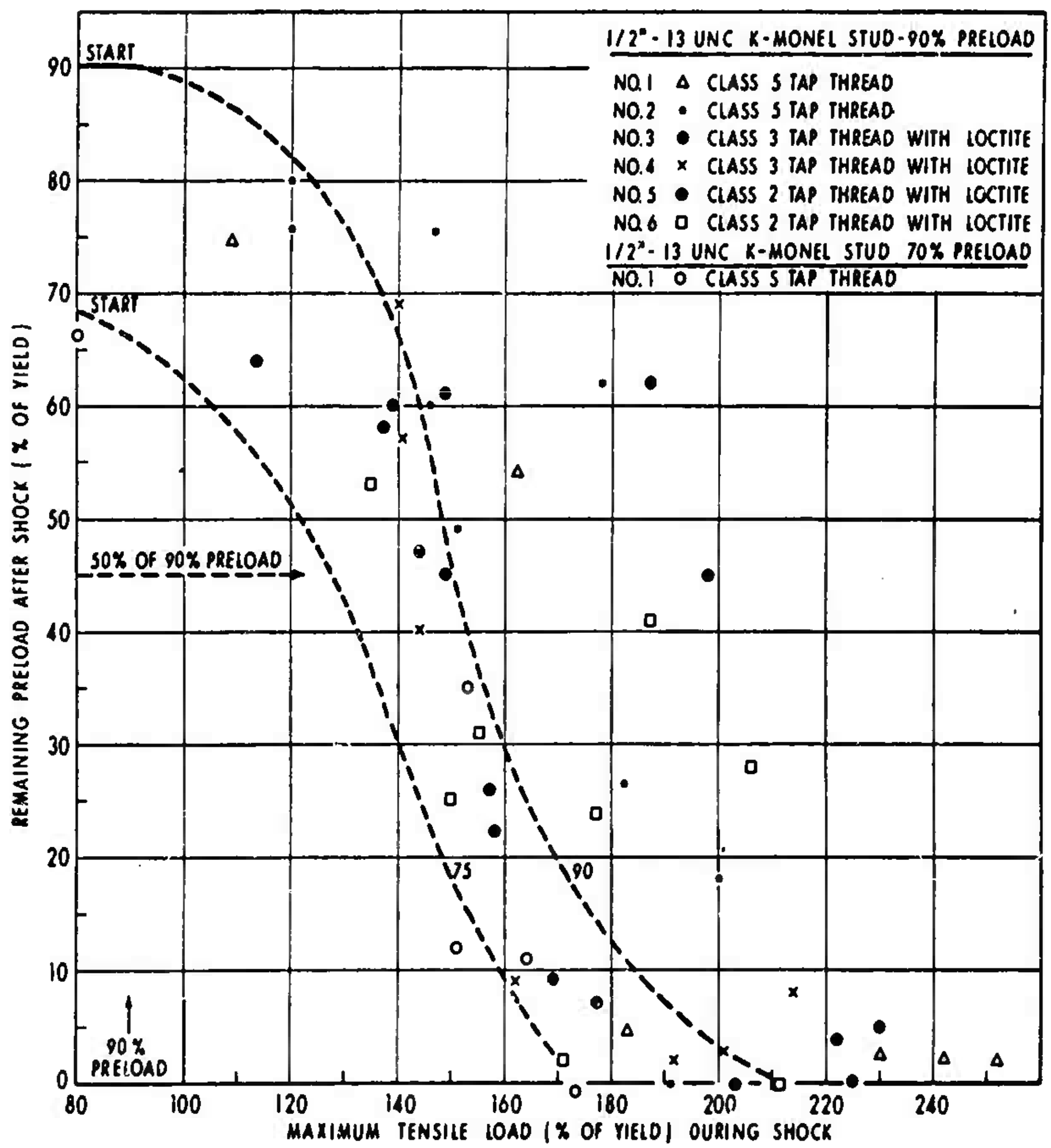

Figure 5

Effect of Shock Tensile Loading on Retained Preload, 1/2" Studs

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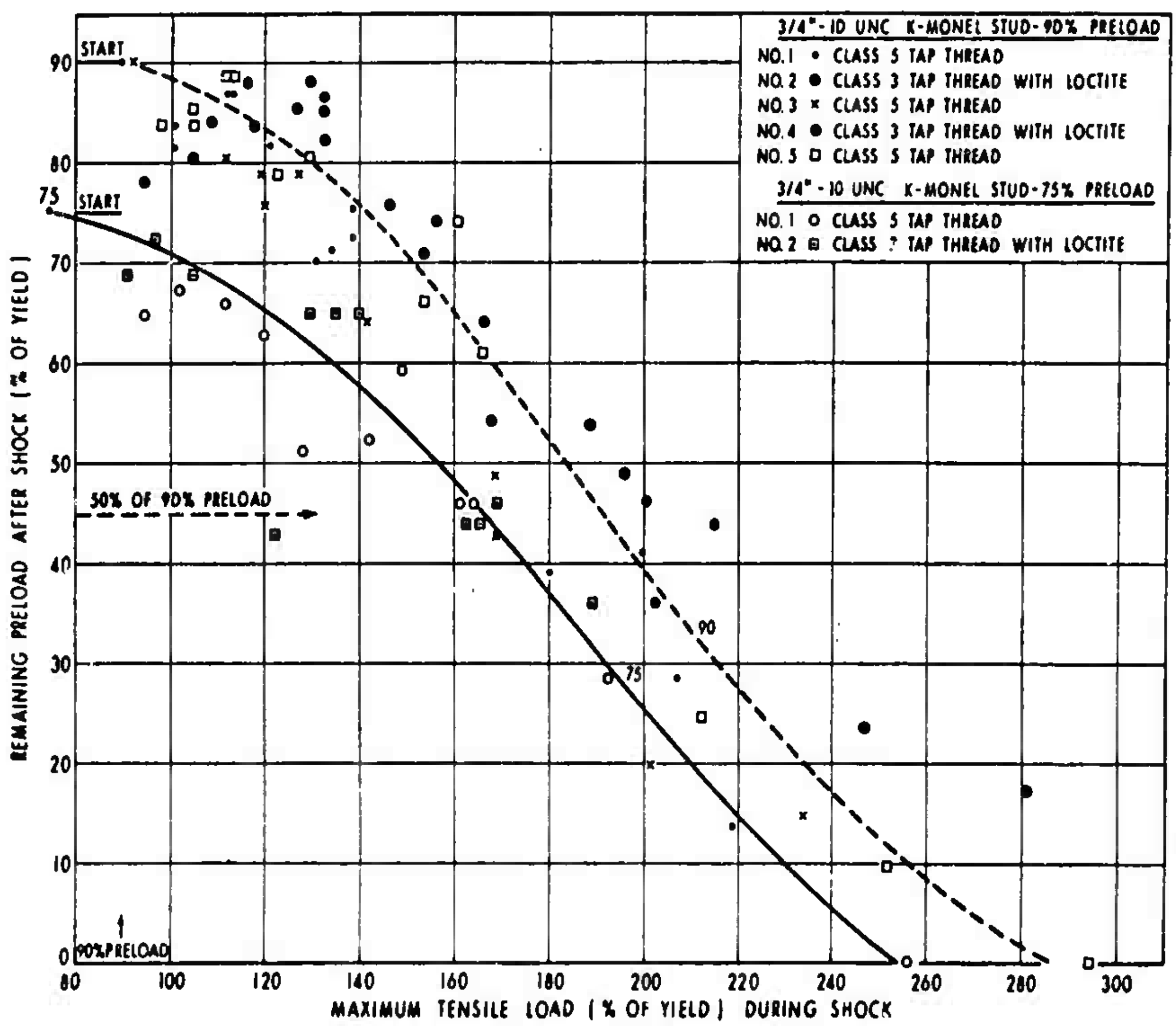

Figure 6

Effect of Shock Tensile Loading
on Retained Preload, 3/4" Studs

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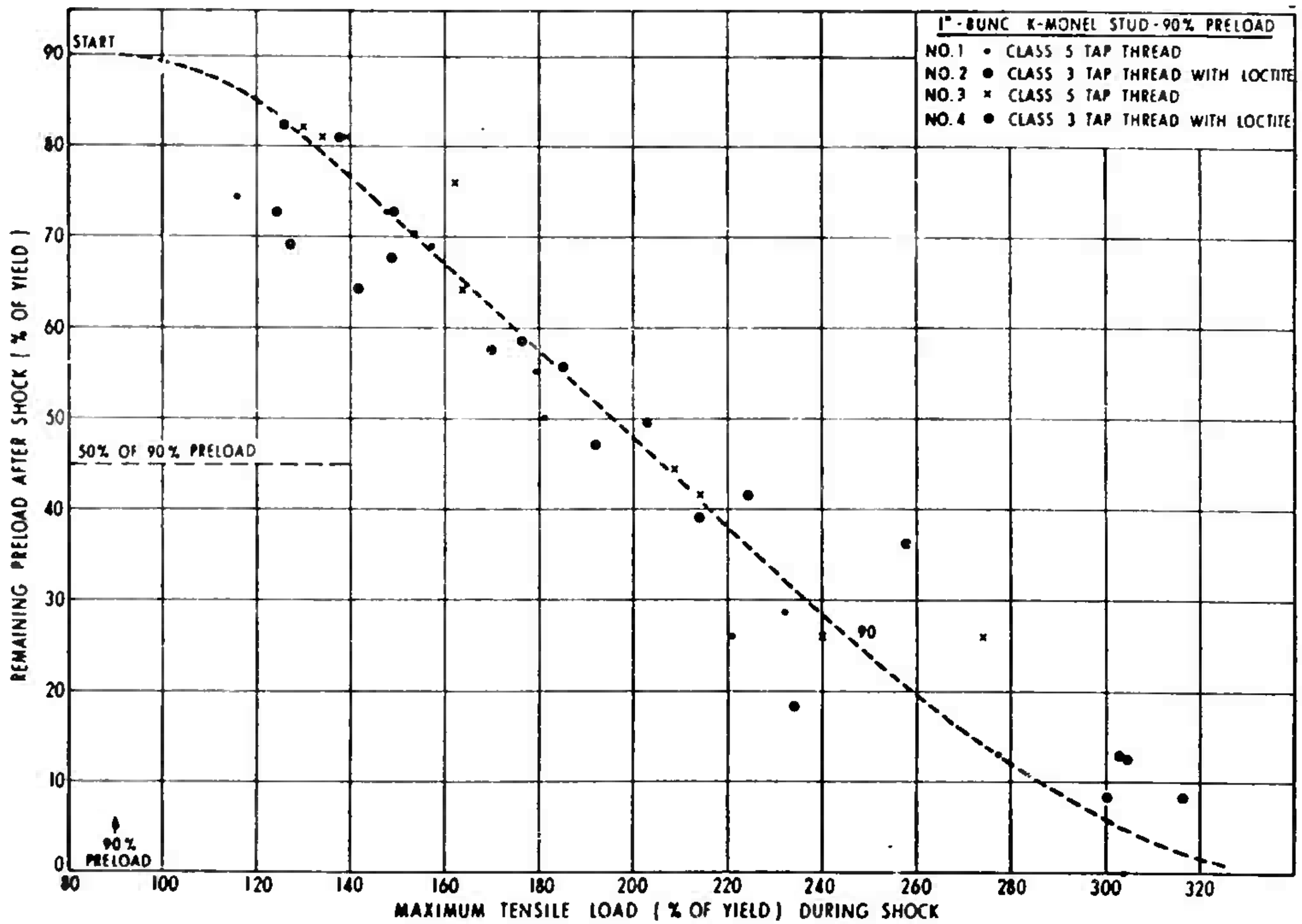

Figure 7

Effect of Shock Tensile Loading on Retained Preload, 1" Studs

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Note: 1" 8UNC K-Monel Stud Preload - 90% of Yield, Class 3A Thread with Loctite

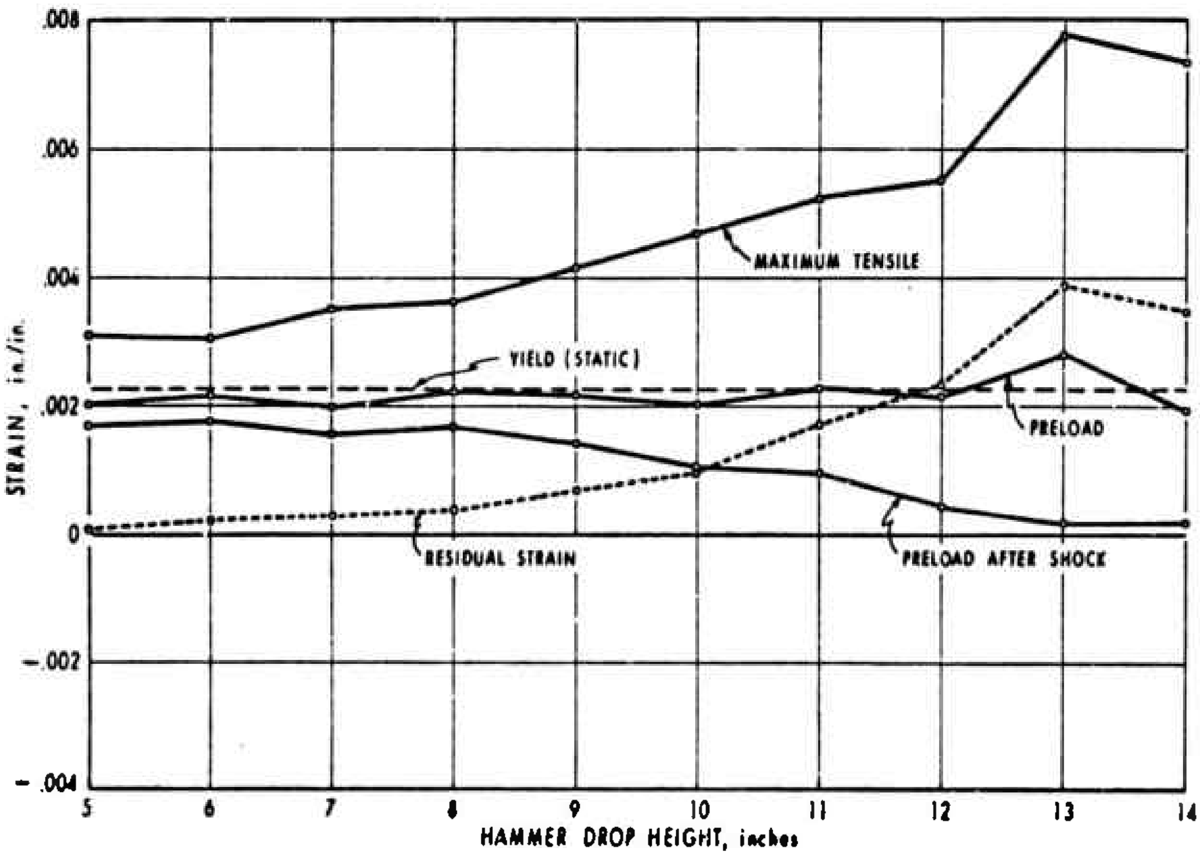

Figure 8

Relation of Shock Strain
to Hammer Drop Height

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Note: 1" 8 UNC K-Monel Stud, Preload - 90% of Yield, Class 5
Thread Tap End

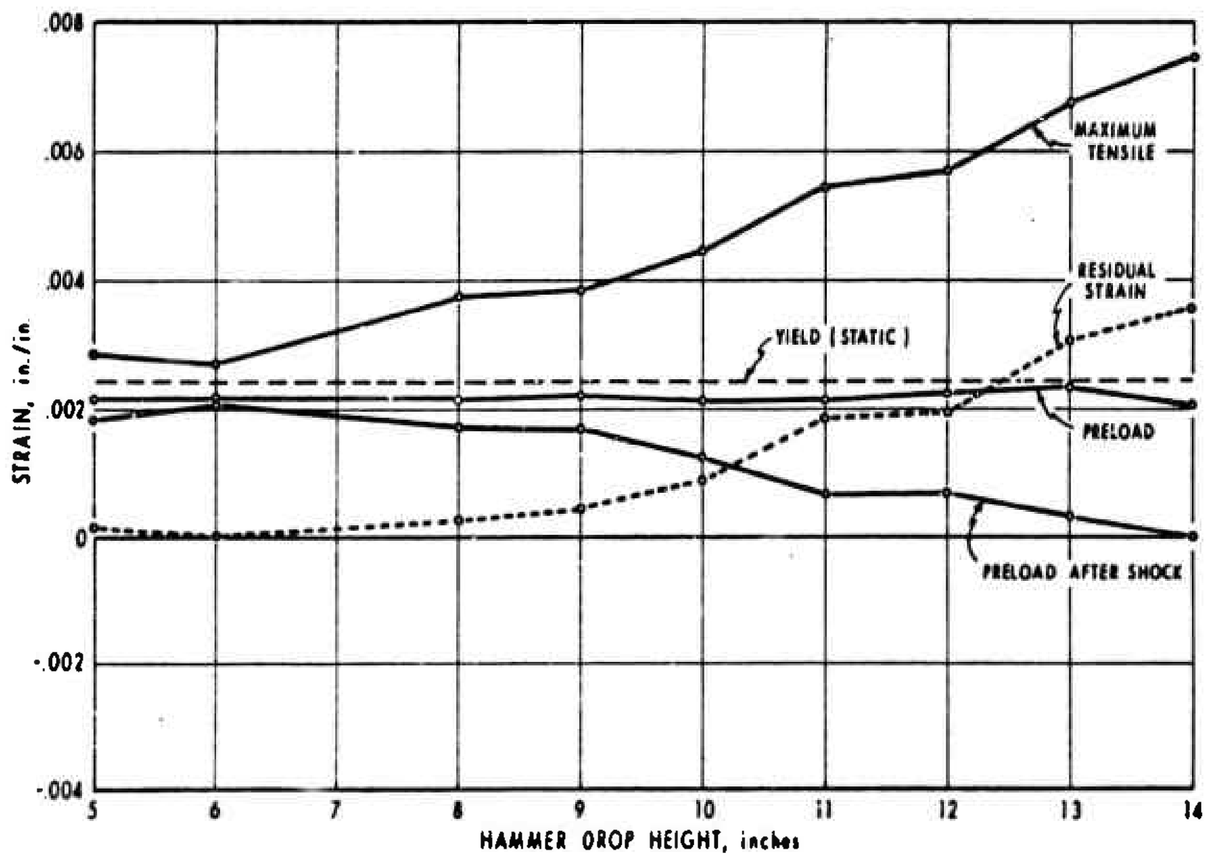

Figure 9

Relation of Shock Strain
to Hammer Drop Height

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NOTES:

Stud	Diameter (in)	1000 psi Load (lb)	Load Factor Based on 1/2" stud	Load Factor Based on 1" stud
A	.5	196.4	1.0	.25
B	.75	441.8	2.25	.5625
C	1.0	785.4	4.	1.0
D	1.25	1227.	6.25	1.5625
E	1.5	1767.	9.	2.25
F	2.0	3142.	16.	4.0
G	2.5	4909.	25.	6.25

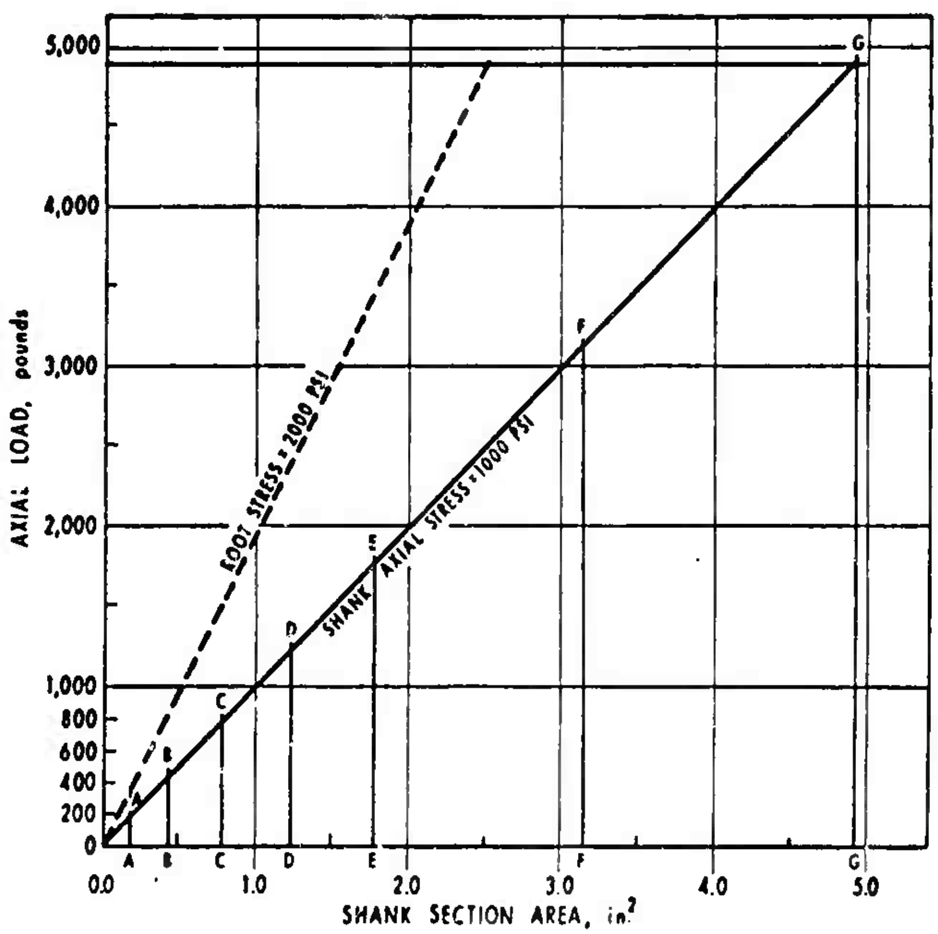

Figure 10

Relation of Axial Load to Stud Shank Area for 1000 PSI Stress at Shank, for 2000 PSI Stress at Root*

*Kα = 2.0

Appendix A

Technical References

1 - NBS Screw-Thread Standards for Federal Services, Handbook H28, 1957, Parts I, II, III
2 - Military Standard MS-17828, NUTS, Self Locking, Nylon Insert, Hexagon, Regular Height, 250°F., Nickel Copper Alloy (R-Monel)
3 - Military Standard MS-17829, NUTS, Self Locking, Nylon Insert, Hexagon, Regular Height, 250°F., Grade 8 Carbon Steel
4 - Military Standard, MS-17830, NUTS, Self Locking, Nylon Insert, Hexagon, Regular Height, 250°F., F-303 Corrosion Resistant Steel
5 - Military Specification QQ-N-286a (Amend. 1) - August 1956, K-Monel, Class A, Age Hardened
6 - Military Specification MIL-B-857A, (SHIPS) Amend 4, 15 Dec 1964, p. 9, Bolts
7 - Military Standard MS-18116 (SHIPS) - 15 June 1964, Studs
8 - Military Specification MIL-S-22473A, "Locktite" Sealing and Retaining Compound
9 - Military Specification, MIL-S-901C, Amend 1, 5 Sep 1963, Shock Tests (High Impact) Shipboard Machinery, Equipment, Systems
10 - Value Engineering Company Reports 1 through 8, VE-R&D -65, April 1965, "Establishment of Standardization Data for Monel and K-Monel Fasteners, NAVY BUSHIPS Contract No. NObs-90493
11 - Roark, R. J., "Formulas for Stress and Strain," Third Edition, McGraw-Hill, 1954, Table XVII, page 351
12 - Timoshenko, S. and J. N. Goodier, "Theory of Elasticity," Second Edition, McGraw-Hill, 1951, Pg. 310-313

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13. ABSTRACT

An investigation was made of the mechanical shock resistance of K-Monel full-body studs set in HY-80 steel under various conditions. Strain gages mounted on the stud shanks were used to measure dynamic loading. Elastic nylon-insert monel stop nuts were used throughout the test. The data indicated that for the conditions of the test Locktite-coated 3A-3B threads are equal in shock resistance to uncoated 5A-5B threads, and that the elastic stop nuts are reusable after repeated shock.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Threaded fasteners						
Fastener systems						
Shock resistance						
Mechanical shock						
Strain-gages						
Strain						
Stress						
Load						
Yield strength						